

Musculoskeletal MR Imaging at 3.0 Tesla

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Introduction

Most conventional MR imaging of the musculoskeletal system is done at 1.5 Tesla. Higher field systems, typically 3.0 Tesla, are now becoming available. 3.0T MRI means a higher signal-to-noise ratio (SNR), which can be used to improve imaging speed or resolution. However, there are changes in relaxation times at 3.0T as well as increased artifacts to consider. Our initial clinical experience at 3.0 Tesla shows that contrast and diagnosis of pathology is similar to 1.5T, with some benefits from improved resolution and SNR.

High Field Imaging

In general, the intrinsic signal to noise ratio (SNR) available in a MRI experiment is a function of the strength of the main magnetic field, the volume of tissue being imaged, and the radiofrequency coil being used. In theory, if the coil and the subject are equivalent, imaging at 3.0T should provide twice the intrinsic SNR of imaging at 1.5T (1). However, changes to tissue relaxation times, sensitivity to magnetic susceptibility, and the chemical shift difference between fat and water all influence image quality at 3.0T. Thus, careful adjustment of the imaging protocols is necessary to optimize imaging at 3.0T.

Tissue Contrast

Prior measurements of relaxation times at 3.0T showed increases of T1 of 70-90% and decreases of T2 of 10-20% compared with 1.5T (2). Recent measurements of these values in musculoskeletal tissues at 3.0T show a decrease in T2 of about 10% and an increase in T1 of about 15-20% (3). The changes in these parameters affect the choice of TR and TE that are appropriate for 3.0T, and ultimately impact the contrast and SNR of the images produced.

In MRI, tissue contrast is determined by a number of variables, including the TR and TE chosen by the scan operator, the T1 and T2 relaxation times of the tissues being studied, and the use of fat saturation. At 3.0T, the chosen TR and TE should reflect the underlying tissues being imaged and the contrast desired. In most cases, since the T1 relaxation times have increased at 3.0T, the TR must be longer to achieve the same type of contrast seen at 1.5T. Similarly, the TE should be slightly shorter to

account for decreases in T2 relaxation times. In gradient echo examinations, the flip angle should be lower to account for the increased T1 relaxation times. Since T2* effects are doubled at 3.0T versus 1.5T(4), TE needs to be shorter at 3.0T to produce similar contrast for those sequences.

Artifacts

Since the resonant frequencies of fat and water are twice as far apart at 3.0T compared with 1.5T, chemical shift of fat pixels in the frequency-encoding direction will be twice as great at a given imaging bandwidth (4). As a result, on non-fat saturated sequences, one should consider doubling the receiver bandwidth compared with 1.5T to at least ± 32 kHz. This reduces the available SNR by the square root of 2, since the overall readout window length is shorter at a higher bandwidth. However, increased bandwidth permits more slices and shorter echo times.

One area where chemical shift artifacts may affect diagnosis is in the spine, where intervertebral disks may appear larger or smaller depending on the bandwidth in the frequency direction (*Palmer, et al. ARRS 2003*). Artifacts from motion or metal in the post-operative patient may present more problems at 3.0T than at 1.5T. Susceptibility from small pieces of metal left in and around the joint will be increased (4). Strategies for dealing with post-operative artifacts at 1.5T will also work at 3.0T, such as increasing the bandwidth and minimizing the use of gradient echo sequences (5).

RF Power Deposition

The resonant frequency at 3.0T (about 125 MHz) is twice that at 1.5T. This means that the radiofrequency (RF) power for excitation at 3.0T is four times higher than at 1.5T (6, 7). Use of shorter imaging sequences such as fast spin echo may reduce the RF power deposition.

Since the RF power deposited is a function of tissue volume excited, this is more of a problem with large body areas such as the hips than smaller areas such as the knee (7).

Fat Saturation at 3.0 Tesla

At 3.0T, the chemical shift between fat and water resonance is twice that of 1.5T, or approximately 440 Hz(1). This means that fat saturation at 3.0T is easier than at 1.5T in the sense the peaks are farther apart. The length of the fat saturation pulses can be shortened from about 16 ms to 8 ms. The overhead time per slice spent in fat saturation at 3.0T during a multi-slice acquisition is less than at 1.5T. This means that if fat saturation is applied, more slices can be acquired at a given TR, slice thickness and bandwidth at 3.0T than at 1.5T.

Imaging of Pathology at 3.0T

Images of pathology at 3.0T appear similar to those at 1.5T (8). Fluid continues to be bright in areas of pathology and tears. Shortening of T2 relaxation times may lead to decreased problems from magic angle effects (9). Tears result in increased T2 relaxation times in tendons (Figure 5). Overall, improved resolution and speed should allow for improved diagnostic accuracy, or at least improved diagnostic confidence.

Improvements in Speed

As mentioned earlier, the SNR at 3.0T is approximately double that of 1.5T. Since SNR is proportional to the square of the scan time, it is possible to go up to four times faster at 3.0T than 1.5T with equivalent SNR. This is only true if the scans at 1.5T are done with multiple averages for increased SNR and the relaxation time changes at 3.0T do not significantly impact the SNR. In practice, it may be possible to go twice as fast at 3.0T.

The principles behind rapid protocol design at 3.0T are as follows. First, minimize the use of signal averages. Second, increase the TR to account for longer relaxation times and improve the SNR. Third, double the receiver bandwidth compared with 1.5T on non fat-saturated sequences. Finally, fast spin echo imaging with small echo spacing is useful for all sequences, including the T1-weighted images. The echo train length must be kept short on the short TE images to avoid blurring, but can be longer on the T2-weighted images. Because of the g-factor in multiple coil acquisition, parallel imaging will cost SNR and should not routinely be used unless signal averages are already minimized.

Improvements in Resolution

The increased SNR available at 3.0T may also be used to improve the resolution of the images that are acquired. In theory, the resolution in one direction can be doubled at 3.0T and generate the equivalent SNR as a 1.5T image. In practice, due to changes in relaxation times, the best strategy for utilizing the increased SNR at 3.0T for improving resolution may be to acquire more, thinner slices. An increase in TR for multi-slice acquisitions allows for more slices to be acquired and offsets the effects of increased T1 relaxation times. The slice thickness may then be halved from 3.0 mm to 1.5 mm and twice as many slices acquired. If only one signal average is used, the total scan time is equivalent and SNR is comparable to 1.5T.

Increased resolution may be helpful in several problem areas of musculoskeletal imaging (10). These include the labrum in the shoulder (Figure 6), the talar dome cartilage (Figure 3), and the acetabular labrum (Figure 4), and the articular cartilage (Figure 11). Imaging of these areas at very high

resolution may require multiple signal averages for either SNR, to avoid phase wrap, or both. If imaging is done with fat suppression, lowering the imaging bandwidth will improve the overall SNR. If T2-weighted imaging is used, increasing the echo train length for additional speed is acceptable. However, if T1-weighted or proton density (short TE) imaging is performed, as short echo train length may be preferable to avoid blurring (11).

Conclusions

Magnetic Resonance Imaging provides a powerful tool for the imaging and understanding of the musculoskeletal system. The fundamental trade-off between image resolution and SNR still limits our ability to image *in-vivo* at 1.5T with high resolution in an efficient manner. 3.0T systems may allow for fast routine imaging or higher resolution studies. Faster imaging will result in less patient motion, increased comfort, and better throughput. Increased resolution may result in more accurate diagnosis, but will require prospective validation.

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